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EFFECT OF COMPRESSION RATIO ON THE PERFORMANCE, COMBUSTION AND EMISSION OF A SINGLE CYLINDER DIESEL ENGINE USING MULTI BLENDED SECOND GENERATION BIOFUEL

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ABSTRACT

This work tries to identify the effect of compression ratio on the emission, performance and combustion characteristics of a diesel engine run on multi blended second generation biofuel. For this experiment a single cylinder, 4-Stroke, water-cooled, DI variable CR diesel engine and an alternate for diesel – multi blend of Waste cooking oil Methyl Ester (WME), Tyre Pyrolysis Oil (TPO) and Cerium oxide (CeO_2) were used. Investigation has been conducted at various CRs (17, 16 and 14) in different loading percentiles by fixing the injection timing at 23 crank angle of BTDC. Investigation shows an improvement in Break thermal efficiency and a decrease in Specific fuel consumption as compression ratio increases. It is observed that a linear improvement in combustion properties like peak cylinder pressure and heat release rate happens when compression ratio increases. Due to high cylinder pressure and temperature the NOx emissions increase at higher compression ratio whereas Carbon monoxide (CO) and Hydrocarbon (HC) emissions are lesser in the same scenario.

KEYWORDS: Waste Cooking Oil, Tyre Pyrolsis Oil, Cerium Oxide, Compression Ratio & Emission

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Original Article

INTRODUCTION

In present works researchers are paying more concentration on the depletion of fossil fuels for the alternative for nonconventional fuels. Diesel [1] [2] [3] is the main source for many applications like agriculture sectors, earth moving equipment, defence and transportation because of its outstanding availability, fuel economy and storage. Hence, this has ruined the human health and environment by its adverse emissions of smoke, HC, CO and NO_x. Fossil fuels are non-renewable and its continuous use will make sure its extinction which will finally end up in a global fuel crisis. Hence, in order to reduce fossil fuel accessibility and demand, the development of alternate fuel is must in this scientific era [12]. Also biofuels which are playing the role of alternate fuel for fossil fuels is more environmental friendly due to the cleaner combustion and less toxic emission [10].

Ambarish Datta and Bijan Kumar Mandal [5] investigated and found that performance of a CI engine increased appreciably by increasing the compression ratio for palm oil biodiesel. Also, it was reported that increase in compression ratio significantly increases the CO, HC emissions and reduction in NOx emission. And also a slight increase in CO2 was observed with higher compression ratio. Kassaby and Nemitallah [11] reported that the increase of compression ratio increases brake thermal efficiency in case of B10, B20, B30 and B50. On an increase

of CR from 14 to 18 the CO2 emission increased by 14.28%, the HC emission reduced by 52%, CO emission reduced by 37.5% and NOx emission increased by 36.84% . The ignition delay decreased by 13.95% when, compression ratio increased from 14 to 18.

Bhaskor J. Bora et al [6] did an experimental investigation for understanding the effect of CR on the performance, combustion and emission characteristics of a raw biogas. At all loads the BTEs are found to be reducing by the reduction in compression ratio. On the part of emission, on an average, there is a reduction in Carbon monoxide as well as hydrocarbon emission by 26.22% and 41.97% for the change in compression ratio from 16 to 18. However, there is an increase in NOX as well CO2 emission by 66.65% and 27.18% respectively for the same change of CR.

On account of above studies an attempt has been made in this paper to experimentally investigate the effect of compression ratio on the performance, combustion and emission characteristics of an unmodified CI engine running with multi blended second generation biofuel. Three different compression ratios have been used in this study, viz. 17, 16 and 14 on a Kirloskar made single cylinder, four stroke, water cooled variable compression ratio TV1 engine.

MATERIALS AND METHODS

Test Fuels

This framework is about the experimentation using multi blends of second generation bio fuels waste cooking oil and tyre pyrolysis oil with additive as ceria nanoparticles. These biodiesel and blends are explained further as follows:

Waste cooking oil for our work is collected from Sathyabhama university canteen which has the major usage in frying chips in temperature ranging from 75^0c to 140^0c. From this waste cooking oil WME (Waste cooking oil Methyl Ester) is prepared with the help of single step trance esterification process as NAOH as catalyst. Tyre pyrolysis oil (TPO) is an oily organic compound derived from waste automobile tyres by pyrolysis process. It comprised naphthalene, sulphur, alkylated benzenes, alkanes from C8 to C15 and n-alkanes from C11 to C24, with few amount of nitrogen, phenanthrenes and oxygenated compounds. As the sulphur content is law in this second generation bio fuel it processes cleaner combustion. CeO_2 is purchased from sigma Aldrich chemicals, Bangalore. The CeO_2 nanoparticles are considered as additive for the reduction of deadly gases on hydrocarbon combustion fuel and there by enhances the fuel economy. This cerium oxide is in the form of Nano powder and particle size is less than 25nm (BET), whereas the density is given as 7.13 g/mL at 25^0C (lit.).

Fuel samples were prepared by multi blending of WME and TPO at various proportions by adding CeO2 as additives. For the better mixing and uniform dispersion during blending we used magnetic stirrer, maintaining the sample at 400C temperature. From the experimental data obtained earlier from our works W80T20CeO2100 blend process comparatively better performance and emission characteristic by comparing with other blend proportions. This blend constitutes 80% WME, 20% TPO and 1PPM of CeO2. So for this study we are choosing W80T20CeO2100 as biofuel. Table 1 depicts the physical properties of W80T20CeO2100 fuel.

Table 1

Fuel	Calorific Value (cal/g) (ASTM D4809)	Density (g/cc) at 40^0C (ASTM D4057)	Kinematic Viscosity (cSt) (ASTM D445)	Flash Point (^0C) (ASTM D93)	Fire Point (^0C) (ASTM D93)	Cloud Point (^0C) (ASTM D97)	Pour Point (^0C) (ASTM D97)
WME	8522.978	0.875	3.54	188	207	-2	-11
TPO	10270	0.91	0.812	45	62	-11	-22
W80T20CE$O_2$100	8815.556	0.885	1.288	121	135	-8	-19

Test Engine and Instrumentation

Experiments were carried out in a single cylinder, 4-stroke, water-cooled, DI diesel engine. Experimental setup layout is shown in Fig1. Table 2 depicts the engine specification provided by manufacturer. This engine model used is Kirloskar TV1which is under Bharat (Trem) Stage I norms. Table 3 depicts the instrumentation facility and its specifications attached with test engine. Table 4 shows accuracy and uncertainties of the equipment used.

Table 2: Engine Specifications

Make and model	Kirloskar, TV1 make, 4-Stroke Diesel
Number of cylinders	One
Combustion chamber	Hemispherical open type
Cooling system	Water-cooled
Lubricating oil	SAE40
Piston Shallow	Bowl-in type
Bore, mm	87.5
Stroke, mm	110
Connecting rod length, mm	238
Swept volume, cm3	661
Clearance volume, cm3	38.35
Compression ratio	18:1(VARIABLE)
Rated power, kW	5.2
Rated speed, rpm	1500
Injection type	Direct Injection
Fuel injection pump	MICO inline, with mechanical governor
Injection pressure, bar	210
Injection timing, CA bTDC	23°
Number of Nozzle holes	3
Spray-hole diameter, mm	0.25
Spray cone angle, °	110
Needle lift, mm	0.25
Valve diameter, mm	34.2
Maximum valve lift, mm	10.1

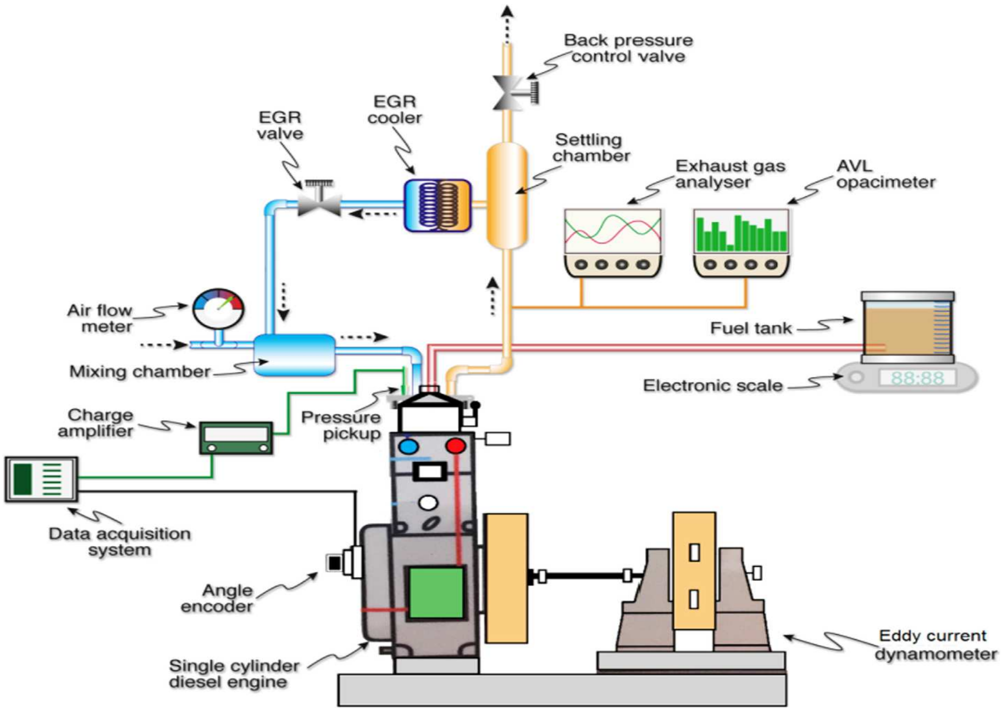

Figure 1: Layout of the Experimental Setup.

Table 3: Equipment Make and Model

Dynamometer	Technomech, TMEC-10, Eddy current type, 7.5 kW, 1500–6000 rpm. Water-cooled.
Dynamometer loading unit	Apex, AX-155, Constant speed type
Load sensor	Sensotronics Sanmar 6000, Load cell, Strain gauge type, S beam, Capacity 0–50 kg
Pressure transducer	PCB Piezotronics, HSM111A22, Range 5000 psi. with low noise cable
Data acquisition system	National Instruments – USB-6210 Bus Powered M Series. 16-bit, 250 kS/s, Piezo powering unit Model AX-409.
Crank angle encoder	Kubler-Germany 8.3700.1321.0360, Dia: 37 mm.
Crank angle sensor	Speed 5500RPM with TDC pulse
Fuel flow transmitter	Yokogawa, EJA110-EMS-5A-92NN, Calibration range 0–500mm of H2O
Air flow transmitter	Pressure transmitter, Range 0–250mm of H2O
Resistant temperature detector	PT100 – Range 0 to 100 °C
Thermocouple	Type K – Range 0 to 1200 °C, O/P 4–20 mA
Gas analyser (NO, CO and HC)	AVL 444N
Smoke meter	AVL 437C

Table 4: Range, Accuracy and % Uncertainties

Equipment	Measured Quantity	Range	Accuracy	Uncertainties, %
AVL 444N gas analyzer	NOx	0–5000 ppm	± 50 ppm	± 5
AVL 437C smoke meter	Smoke	0–100%	± 1%	1.00
Speed measuring unit	Engine speed	0–9999 rpm	± 10 rpm	0.15
Pressure transducer	Cylinder pressure	0–250 bar	± 0.1 bar	0.10
Crank angle encoder	Crank angle	0–360°	± 1°	0.20

Test Procedure

The experiment was carried out at FIVE different percentiles of the engine's rated load as 0%, 25%, 50%, 75% and 100%. In this study we kept the injection pressure as constant throughout. Injection timing of the test engine is kept as 23° Crack Angle BTDC as suggested by manufacturer. The lubricating oil was maintained between 85^0C and 90 °C. To improve the reliability of the recordings, tests were carried out at constant ambient temperature. For engine stabilization, the engine always ran for 10 minutes before recording of readings. Performance, Combustion and Emission values are recorded for various compression ratios. Here in our study we selected three distinct compression ratios 17, 16 and 14. To improve the reliability of tests each test was repeated three times and average of which is accounted.

RESULTS AND DISCUSSIONS

Performance Parameters

- **Break Thermal Efficiency (BTHE):** According on the experimental data acquired as compression ratio raises fracture thermal efficiency gains, which can be due to the decrease in ignition delay. In our experimental study we first left our operation calculations in three different compression rates, 17, 16 and 14. Figure 2 reflects the variant of BTHE with compression ratios in different load requirements. The very low volatility of the duel blended biodiesel induces elevated efficiencies in high compression rates, which contributes a greater combustion in elevated temperature. Reduction in heat reduction and growth of brake energy with applied loading also among the main reason behind increase in efficacy in higher compression levels, which contributes biogas to experience combustion.

In 100% load, the BTHE can be seen to become 29.46 percent, 28.09 percent and 26.79 percent, in CRs 17, 16 and 14, respectively. Figure 2 reflects the variant of BTHE with loading conditions in different compression ratios.

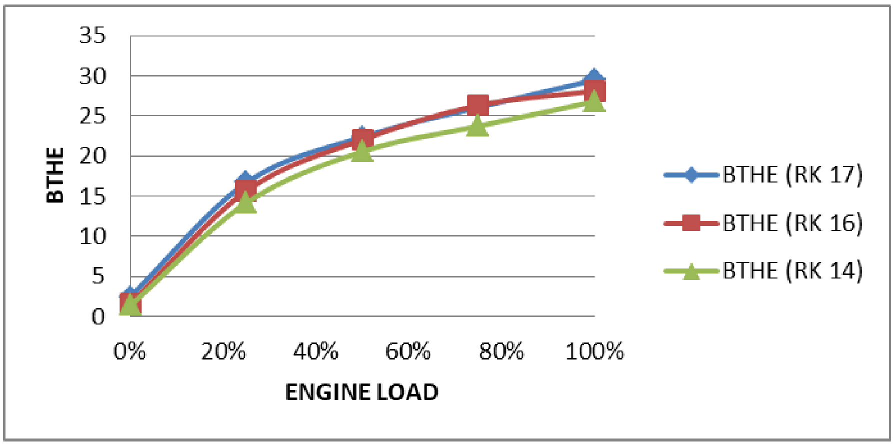

Figure 2: Variation of BTHE vs. Engine Load at Different CRs.

Specific Fuel Consumption (SFC): From the experimental data it is clear that SFC depends on change in compression ratios. Although the variation is minute, its influence cannot be neglected. Figure 2 shows the variation of specific fuel consumption with engine load percentile for the three different compression ratios. Fuel consumption per unit power depends on the maximum cylinder pressure, which is a function of compression ratio. So as the compression ratio increases SFC decreases. Figure 3 shows the variation of SFC with percentage of beak power at three different compression ratios, 17, 16 and 14.

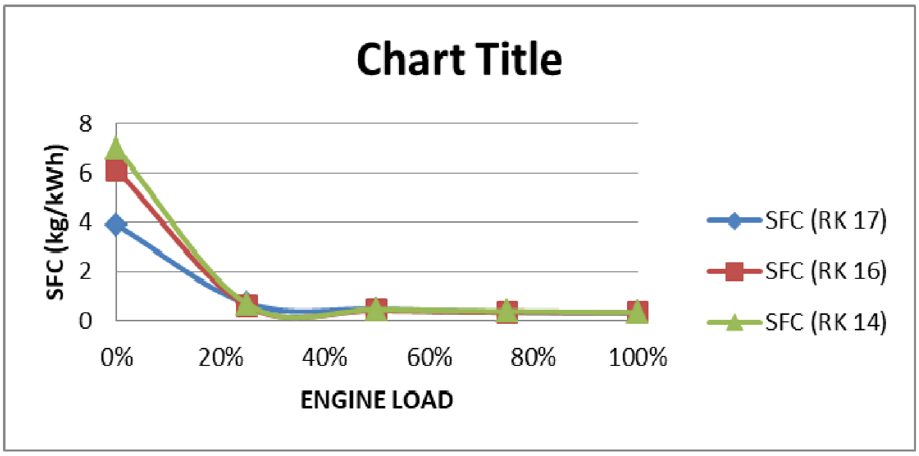

Figure 3: Variation of BSFC vs. Engine Load at Different CRs.

Combustion Parameters

- **Peak Cylinder Pressure:** Cylinder pressure data evaluation is a very important function in assessing the motor behaviour as the engine operation and also the emission characteristics tremendously depends upon cylinder pressure background [6]. Since the density of the gas air mix increases with increase in compression ratio, which contributes to better mixing of both burnt and unburned fuels followed closely by large air pressure. At low compression rates cylinder pressure decreases because of slow combustion and also improper mixing of burnt and unburned fuels.

In our experimentation we also could definitely depicted exact routine of shift of peak air pressure along with compression ratios. The figure 4 shows the variation of peak air pressure, fold angles at various compression ratios.

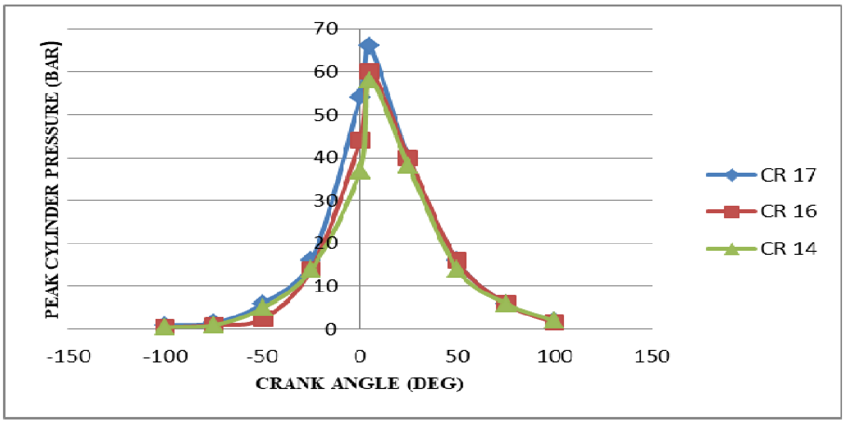

Figure 4: Variation of PP vs. Crank Angles at Different CRs

- **Net Heat Release Rate:** Figure 5 shows the variation of net heat release rate with different crank angle at various compression ratios. From figure it is clear that heat release rate increases with decrease in CR. At higher compression ratio, injection of fuel air mixture causes fast combustion of charge which leads decrease in net heat release rate. Lower compression ratios causes' ignition delay, which leads excess fuel injection. This causes delay in premixing of air-fuel mixture and in turn tends to increase the heat release rate [4]. At CR 17,16 and 14 the values of higher net release rates are 38 J/Deg.CA, 44 J/Deg.CA, 47 J/Deg.CA.

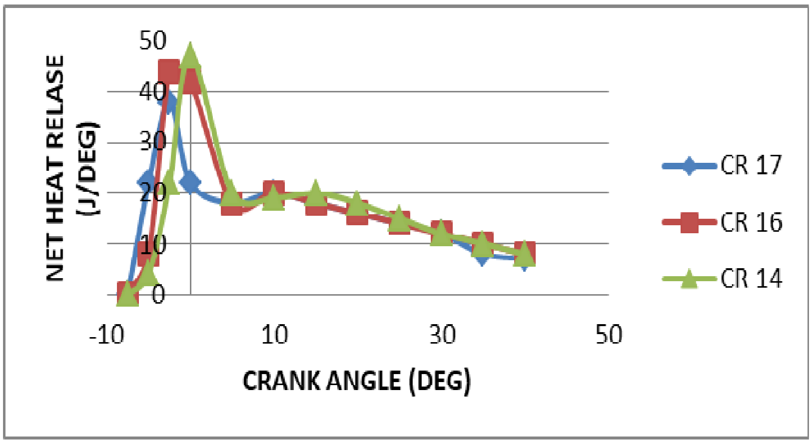

Figure 5: Variation of NHR vs. Crank Angles at Different CRs.

Emission Parameters

Due to the increased air pollution and ozone depletion in 1964 USA decided to frame a standard for vehicle pollution. On this point of view there has been a large of numbers pollution norms were implemented to safe guard the environment. Presently, E6 standards are implemented in most of nations across the world [7]. On this ground in our studies, we carried out emission analysis for the biofuel at various compression ratios. Influence of compression ratio on Carbon monoxide, Hydrocarbon and Nitrous oxide were studied and explained in detail.

- **Carbon Monoxide Emission (CO):** Deficiency of oxygen causes incomplete combustion and which leads to the formation of carbon monoxide in emission gas [8]. It is observed that at low loads carbon monoxide emission is high, it reduces at medium range loads and again increases maximum at higher loads. At law loads cylinder temperature is less, leads to improper combustion which increases carbon monoxide emission. At higher load, the charge becomes too rich to undergo complete combustion which is another reason for formation of carbon

monoxide. From out studies CO emission increases with decrease of CR. Higher CR processes better combustion by improved growth of temperature during the compression which leads to better combustion. This leads to the reduction of carbon monoxide in emission gas at higher loads. For our fuel at full load a reduction of 83.25% CO emission is reported for the change of CR from 14 to 17. This effect of change of compression ratio is same as investigated by Jindal S, et al. [9]

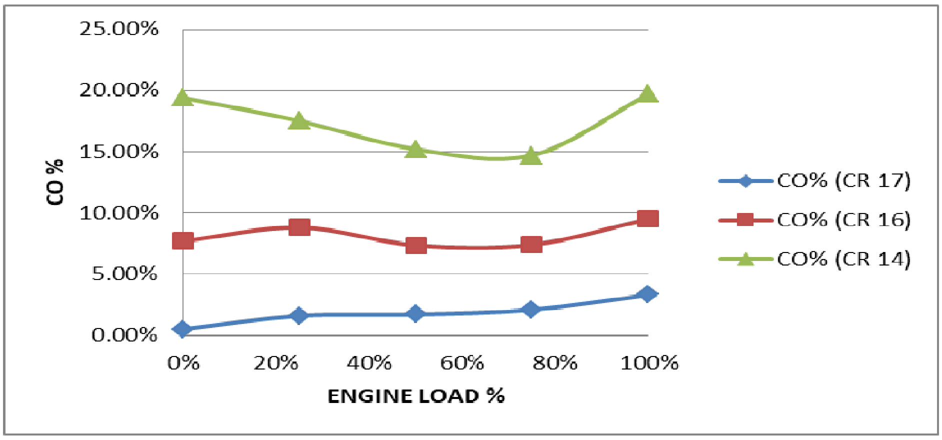

Figure 6: Variation of CO vs. Engine Load at Different CRs.

- **Hydrocarbon (HC):** This is also the by-product of incomplete combustion. In this study, The HC emission increases with increase in engine load and decreases with increase of CR. At 100% load the values for HC emissions are 32,75 and 141 at CR 17,16 and 14.It reports there is a advantage of 77.30 % reduction in HC emission by increase of CR from 14 to 17 at 100% load. The reason for this is same as CO emission as depicted earlier.

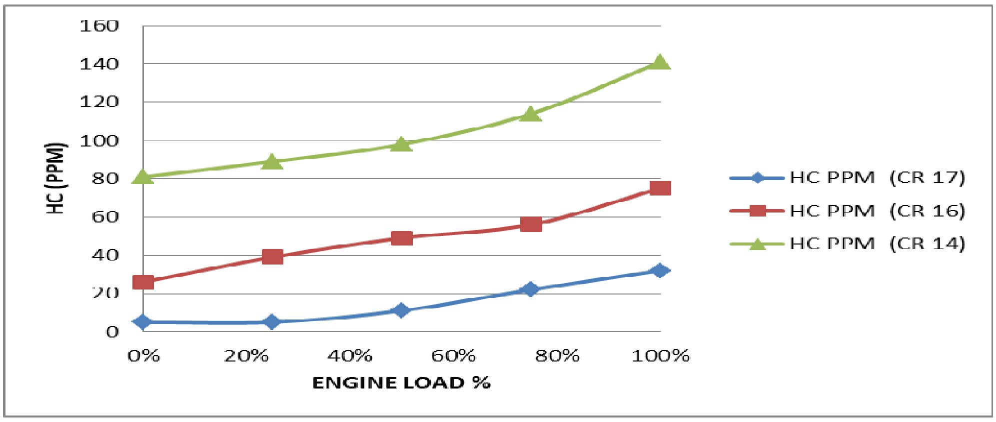

Figure 7: Variation of HC vs. Engine Load at Different CRs.

- **Nitrous Oxide (NOx):** Figure shows the change of NOx emission with engine rated load at different CRs for our fuel. NOx emission is a function of peak cylinder pressure and so its variation with CR is similar to cylinder pressure variation. Increased cylinder temperature and pressure results the formation of more valance oxygen and nitrogen atoms by dissociation of air, which eventually produces more NOx emission.[2] So higher compression ratio leads to higher emission of NOx. This variation can be observed through all ranges of engine loads. At full load values for NOx emission were 1339, 1194 and 1184 corresponding to CR 17,16 and 14. A decrease of 11.58% is reported for the reduction CR from 17 to 14.

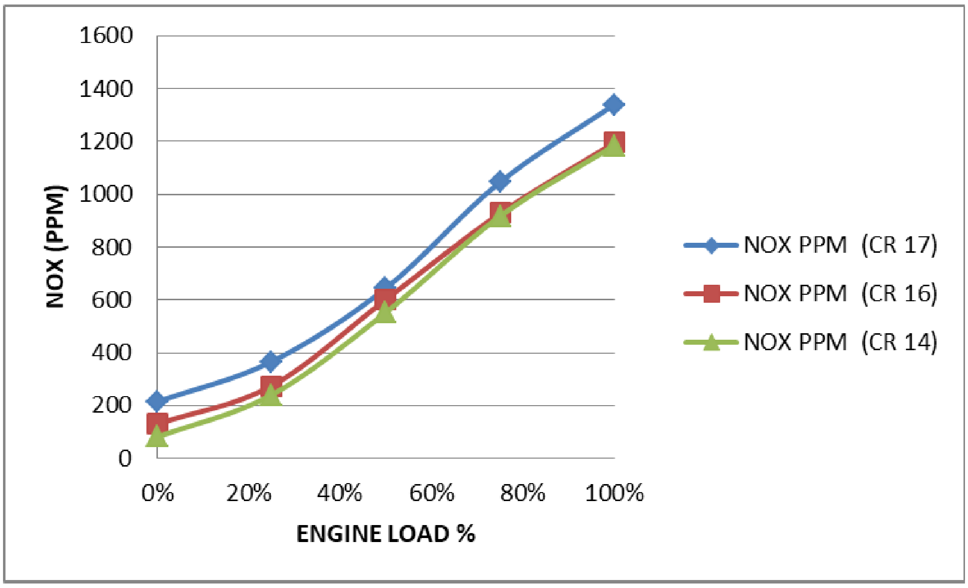

Figure 8: Variation of NOx with Engine Load at Different CRs.

CONCLUSIONS

This study attempted to understanding the effect of change Compression Ratio on the emission, performance and combustion Characteristics of a multi blended second generation biofuel. For this investigation a single cylinder, 4-Stroke, DI variable CR diesel engine is used. As fuel an alternate for diesel with Waste cooking oil Methyl Ester (WME) by adding Tyre Pyrolysis Oil (TPO) and Cerium oxide (CeO_2) was used. W80T20$CeO_2$100 blend processes higher performance and emission characteristics compared to other proportions. At 100% load, the BTEs are found to be 29.46%, 28.09% and 26.79% at CRs 17, 16 and 14, respectively. Considering the specific fuel consumption, an increase of SFC with reduction of compression ratio is noted in narrow scale. Regarding emission analysis there is a reduction in CO as well as HC by 83.25% and 77.30% respectively for the change in compression ratio from 14 to 17 in full load. A decrease of 11.58% of NOx emission is noted for the reduction CR from 17 to 14. Based on the experimental results and theoretical inferences, it is clear that performance parameters and emissions of a diesel engine which runs on W80T20$CeO_2$100 blend are a function of compression ratio. In the overall analysis high compression ratio interface is more beneficial as it processes better performances, cleaner combustion and reduced NOx emission.

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